GYPSUM PLASTERBOARD DECONSTRUCTION TO RECYCLING ECONOMIC STUDY IN EUROPE

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ABSTRACT

Gypsum plasterboard are widely and increasingly used within the construction sector, as partitions, lining of walls, ceiling or flooring systems, representing consequently the largest proportion of the recyclable gypsum waste arisen nowadays in Europe.

This paper studies the reverse logistics processes taking place in the End-of-Life (EoL) phase of the recyclable gypsum plasterboard, by analysing and discussing the existing business model for the distinct gypsum waste routes, either deconstruction or demolition, based on economic parameters and assumptions from a set of case studies where best deconstruction practices have been implemented. This analysis has been developed in the framework of the European Life+ GtoG Project ENV/BE/001039: "From Production to Recycling, a Circular Economy for the European Gypsum Industry with the Demolition and Recycling Industry".

The study highlights the need for an effective deconstruction process to optimize the plasterboard waste recycling, as well as the impact that taxes charged to the disposal of construction and demolition waste have on the economics from deconstruction to recycling.

Keywords: Gypsum waste, End-of-Life, deconstruction, demolition, economics.

INTRODUCTION

Construction and Demolition (C&D) waste accounts for around one third of the total wastes generated in Europe [1], being thus one of the largest waste fraction found in any country, and a sector where there are certainly opportunities for an efficient resource management, in order to meet with the 70% target set by the Waste Framework Directive 2008/98/EC [2]. Applying deconstruction instead of demolition practices increases the potential for the waste further use, which in turn, creates economic value and established markets for the waste streams, as well as environmental benefits. In particular gypsum products, considered amongst the very few construction material whose closed-loop recycling is possible, have come into widespread used in the construction activity. European member states (Belgium, Denmark, Greece, Spain, France, the Netherlands, Poland the United Kingdom) as assessed in the GtoG project generated 1.15 million tonnes of plasterboard waste in 2012 [3].This is predominantly plasterboard in the form of offcuts from construction sites and stripped-out plasterboard from demolition and renovation-sites [4].

Deconstruction, also referred to as selective demolition, is the process of dismantling building components in the reverse order as how they are originally constructed [5]. It is identified as an effective means for reducing C&D mixed waste at a time of diminishing landfill capacities and increasing environmental awareness [6]. Under the GtoG project, the implementation of best practices for a controlled deconstruction process of such gypsum based systems is promoted, which might ease a greater re-use and recycling, to transform the gypsum demolition waste market in order to achieve higher recovery rates of gypsum waste.

Findings from the GtoG research actions evidence that the foremost drivers leading to the implementation of deconstruction practices are environmental and economic reasons. Costs associated with deconstruction have been pointed out as one of the main constrains, as this practice is generally perceived as more costly mainly in countries where demolition is a frequent practice. However, in countries where deconstruction is the most common practice, it is generally perceived as a way of optimizing the cost [7]. For the former, today deconstruction is starting to receive attention and government policy is beginning to address the advantages of deconstruction by increasing or forbidding the disposal if the materials are useful [8]. Notwithstanding, techniques and tools for dismantling the existing structures are still under development, with a limited number of studies and researches carried out [9].

On that basis, and within the scope of the GtoG project, deconstruction operations were implemented in a set of pilot projects located in Belgium, France, Germany and the United Kingdom. Specialized companies undertook such deconstruction operations, set on different site types so as to provide a representative analysis. This paper compares the supplied data from two case studies in order to evaluate how selected cost parameters can influence the overall cost, and prove the economic benefits of deconstruction versus demolition, for construction gypsum systems.

METHODOLOGY

In the study, two differentiated routes are defined in figure 1. Deconstruction involves the removal of the plasterboard by dismantling its components, adopting the practices of source separation and subsequent transport to recycling facility whether passing by transfer station or not. Not only highest percentage of recovered gypsum waste can be achieved when it is source segregated, but also easies collection and storage both on-site and for the transport. Whilst when demolishing, no segregation is implemented obtaining a gypsum waste contaminated with other waste fractions, which becomes non-recyclable and it is usually sent to landfill. If waste is deposited in a transfer station, the transport cost to the recycling facility is assumed by the transfer operator, and it is indirectly included in the transfer station fee.

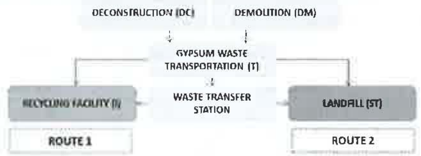

Figure 1. Routes defined under the study.

The competitiveness of the deconstruction route will mainly depend on the logistics, waste collection and the fee per tonne applied for the acceptance of the waste at the recycling facility or landfill. Gypsum waste acceptance criteria and the fee applied vary depending on the country where the assessment is carried out.

According to the above, the cost estimation has been divided into 5 operations. Table1 shows the breakdown of these operations with the related cost influencing variable.

Table 1. Summary of economic operations and variables studied.

Operations	Variables
Dismantling /Crushing, collapsing	Productivity (h/m2)
	Labour rate and equipment (€/m^2)
Sorting and storage operation on-site	Productivity (h/m2)
	Labour rate and equipment (€/m^2)
Loading of the skips	Productivity (h/m2)
	Labour rate and equipment (€/m^2)
Transport	Waste with coefficient of expansion (t)
	Skips per roundtrip (No.)
	Roundtrips (No.)
	Distance to the transfert station or recycling unit (h)
	Haulier (€/h)
Waste management option	Destination (transfer station, recycling facility, landfill)
	Final Route (recovering, recycling, landfill)
	Gate fee, taxes (€/t)

The two buildings under study are offices to be refurbished, and they are located in France and Germany. The operations applied consist on manual best means to dismantle. These techniques allow collection of plasterboard in one piece which saves time when segregating and sorting, as well as enables optimization of the room in the skips, so that it is possible to limit the number of roundtrips. Such technical options may also affect how much of the materials are recovered and the cost of the operations compared with mechanical dismantling, which on the contrary requires more time to separate the different waste streams and increases the risk of contamination by other material.

For the demolition alternative in both different national contexts, assumptions were considered according to existing conventional procedures and data supplied by the demolishers, as those procedures were not implemented.

A summary of the description and criteria taken into consideration for the study is presented in the following table 2.

Table 2. Case studies description and criteria for the cost analysis.

General data	Case study 1		Case study 2	
Country	France		Germany	
Description of the building	9 floors building, offices Construction from 1968		Five single-floor buildings, offices Construction from 1965	
Square meters of gypsum system (m^2)	6,750		3,450	
Type of gypsum system	Double plasterboard partition, metallic frame, glass wool insulation		- Plasterboard ceiling, wooden frame, mineral wool insulation - Plasterboard laminate, metallic frame - Plasterboard partition, wooden frame, wood wool insulation	
Waste fractions	**Tonnes**	**Density (t/m3)***	**Tonnes**	**Density (t/m3)***
Plasterboard partition	67.52	0.52	11.64	0.30
Plasterboard ceiling	0.00		12.00	0.25
Laminates (10 cm Mineral wool)	0.00		13.00	0.08
Mineral/glass/wood wool	1.50	0.08	8.00	0.10
Metal frame	4.49	0.15	1.00	0.08
Wooden frame	0.00		120.00	0.15
Recyclable Gypsum Waste	**67.52**		**23.64**	
Non-recyclable Gypsum Waste			**13.00**	
Mixed Waste	73.51	0.15	165.64	0.25
Deconstruction description				
Step 1. Dismantling	Manually (automatic screwdriver and pickaxe)		Manually (crowbar, pickaxe or sledgehammer)	
Step 2. Sorting	Manually (hopper)		Manually (wheelbarrow and shovel)	
Step 3. Loading	Mechanically (bobcat)		Manually and mechanically	
Step 4. Transport				
Recyclable gypsum	10m³ skip/2 per roundtrip		36 m³ skip/2 per roundtrip	
Non recyclable gypsum			36 m³ skip/2 per roundtrip	
Metal frame	30m³ skip/1 per roundtrip		36 m³ skip/1 per roundtrip	
Insulation	30m³ skip/1 per roundtrip		36 m³ skip/2 per roundtrip	
Wooden frame			36 m³ skip/2 per roundtrip	
Step 5. Waste management option	Recycling facility		Recycling facility via transfer station	
Duration (months)**	6		4	
Demolition assumptions				
Step 1. Crushing, collapsing	Manually and mechanically		Manually and mechanically	
Step 2. Sorting	Manually		Manually	
Step 3. Loading	Mechanically		Manually and mechanically	
Step 4. Transport	30 m³ skips/1 per roundtrip		20 m³ skips/1 per roundtrip	
Step 5. Waste management option	Landfilling via transfer station		Landfilling via transfer station	
Duration (months)**	1.2		0.8	

*With coefficient of expansion **Demolition on-fifth of the time required for deconstruction [5,7]

Plasterboard laminates are recycled when they can be separated from the insulation. Nonetheless, recyclers participating in the GtoG project don't accept it for recycling, thus becoming a non-recyclable gypsum waste under the present study.

The size chosen for the skip capacity is mainly based on the volume of the waste to be stored and transported, but it is ultimately a decision of the construction company, and therefore other criteria may be applied. To optimize the cost of transportation, it is possible to transport one or two loads of waste at a time.

It should be noted that density with coefficient of expansion is an important parameter to be calculated when estimating the transport, as waste increases its volume once it is been removed. There is not an existing standardize value, hence for the purpose of the

study, they have been set by deconstruction consultants according to their experience, and the way deconstruction techniques were implemented which influences the size and shape of the removed plasterboard.

RESULTS

Tables 3, 4 and 5 present the calculations for the study, based on the volume of waste generated in the two pilot projects. The estimated costs are taken from data provided by deconstruction contractors, and vary in relation to their experience and national market conditions. Assumptions have been also considered, as specified in the tables.

Table 3. Costs for deconstruction: Dismantling-Sorting-Loading and Transport stages.

DECONSTRUCTION: Dismantling - Sorting - Loading			Case study 1	Case study 2
Dismantling (to strip out)				
	Productivity (h/m²)*		0.020	0.020
	Labour rate and equipment (€/h)		25.00	28.00
		Total cost of dismantling (€)	**3,375.00**	**1,932.00**
Sorting and storage operation on site				
	Productivity (h/m²)		0.083	0.08
	Labour rate and equipment (€/h)		25.00	28.00
		Total cost of sorting (€)	**14,006.25**	**7,728.00**
Loading of the skips				
Plasterboard	Productivity- Manual labour (h/t)			1.00
	Labour rate (€/h)			28.00
	Productivity mechanical equipment(h/t)		0.05	0.16
	Equipment (€/h)		40.00	55.00
Metal Frame	Productivity- Manual labour (h/t)			1.50
	Labour rate (€/h)			28.00
	Productivity- Mechanical equipment(h/t)		0.06	0.25
	Equipment (€/h)		40.00	55.00
Insulation	Productivity - Manual labour (h/t)			4.25
	Labour rate (€/h)			28.00
	Productivity - Mechanical equipment (h/t)		0.10	1.25
	Equipment (€/h)		40.00	55.00
Wooden Frame	Productivity - Manual labour (h/t)			1.30
	Labour rate (€/h)			28.00
	Productivity - mechanical equipment (h/t)			0.20
	Equipment (€/h)			55.00
		Total cost of loading (€)	**151.82**	**8,594.10**

* Assumption according to average productivity from the GtoG pilot projects

DECONSTRUCTION - Transport		Case study 1	Case study 2
Transport			
Recyclable Plasterboard	Number of roundtrips (No.)	7.00	4.00
	Distance to the transfert station or recycling unit (h)	2.00	1.50
	Cost of the haulier per hour (€/h)	90.00	80.00
Non-Recyclable Plasterboard	Number of roundtrips (No.)		3.00
	Distance to the transfert station or recycling unit (h)		1.00
	Cost of the haulier per hour (€/h)		80.00
Metal Frame	Number of roundtrips (No.)	1.00	1.00
	Distance to the transfert station or recycling unit (h)	0.50	0.50
	Cost of the haulier per hour (€/h)	90.00	80.00
Insulation	Number of roundtrips (No.)	1.00	1.00
	Distance to the transfert station or recycling unit (h)	1.50	0.50
	Cost of the haulier per hour (€/h)	90.00	80.00
	Number of skips per roundtrip (n)		2.00
Wooden Frame	Number of roundtrips (No.)		12.00
	Distance to the transfert station or recycling unit (h)		0.50
	Cost of the haulier per hour (€/h)		80.00
	Number of skips (No.)	2.00	2.00
	Cost rental per month (€/month)**	50.00	50.00
	Total cost of transport (€)	**2,040.00**	**1,680.00**

** Average cost from pilot project data

Table 4. Costs for deconstruction: Waste management option.

DECONSTRUCTION - Waste management option		Case study 1	Case study 2
Waste management option			
Recyclable Plasterboard	Destination (transfer station, recycling facility)	Recycling facility	Transfer station
	Final Route (recovering, recycling)	Recycling	Recycling
	Cost per ton (€/t)	55.00	55.00
Non Recyclable Plasterboard	Destination (transfer station, recycling facility)		Transfer station
	Final Route (recovering, recycling)		Landfilling
	Cost per ton (€/t)		110.00
Metal Frame	Destination (transfer station, recycling facility)	Transfer station	Transfer station
	Final Route (recovering, recycling)	Recycling	Recycling
	Cost per ton (€/t)	-150.00	-150.00
Insulation	Destination (transfer station, recycling facility)	Transfer station	Tansfer station
	Final Route (recovering, recycling)	Landfilling	Landfilling
	Cost per ton (€/t)	95.00	360.00
Wooden Frame	Destination (transfer station, recycling facility)		Transfer station
	Final Route (recovering, recycling)		Recovering
	Cost per ton (€/t)		40.00
	Total cost of the waste management option (€)	**3,182.60**	**10,260.20**
	TOTAL DECONSTRUCTION COST (€)	**22,755.67**	**30,194.30**
	Cost per m² of platerboard system (€/m²)	**3.37**	**8.75**

Table 5. Costs for demolition.

DEMOLITION		Case study 1	Case study 2
Crushing, collapsing			
	Productivity (h/m²)*	0.008	0.008
	Labour rate and equipment (€/h)	25.00	35.00
	Total cost of crushing, collapsing (€)	**1,350.00**	**966.00**
Sorting and storage operation on site			
	Productivity (h/m²)	0.08	0.08
	Labour rate and equipment (€/h)	25.00	28.00
	Total cost of sorting (€)	**13,500.00**	**7,728.00**
Loading of the skip			
	Productivity (h/t)		1.30
	Labour rate (€/h)		28.00
	Productivity (h/t)	0.06	0.20
	Equipment (€/h)	40.00	55.00
	Total cost of loading (€)	**176.42**	**7,851.34**
Transport			
	Number of skips per roundtrip	1.00	2.00
	Number of roundtrips (No.)	16.00	17.00
	Distance to the transfert station or recycling unit (h)	1.50	1.00
	Cost of the haulier (€/h)	90.00	80.00
	Number of skips (No.)	2.00	2.00
	cost rental per month (€/month)**	50.00	50.00
	Total cost of transport (€)	**2,280.00**	**1,440.00**
Waste management option			
	Destination (transfer station, landfill)	Transfer station	Transfer station
	Final Route	Landfill	Landfill
	Gate fee, taxes (€/t)	95.00	110.00
	Total cost of waste management option (€)	**6,983.45**	**18,220.40**
	TOTAL DEMOLITION COST (€)	**24,289.87**	**36,205.74**
	Cost per m² of platerboard system (€/m²)	**3.60**	**10.49**
	Cost increase of demolition compared with deconstruction (%)	**6.74%**	**19.91%**

* Assumption according to average productivity from the GtoG pilot projects ** Average cost from pilot project data

The comparative analysis shows that different dismantling procedures and on-site logistics results on variable waste density and number of skips respectively, which directly impact on the cost assessment.

The principal economic differences between the dismantling and loading operations from the deconstruction route can be attributed to the techniques carried out and equipment used. Only mechanical means in the first case, whereas manually and mechanical ones in the second case. Regarding the transport cost per tonne, in case study 2 is lower as skips of higher capacity are used, reducing the number of roundtrips as well as the haulier cost.

On the other hand, conventional demolishing is determined by the final disposal fees of the mixed waste that are noticeable more costly than in the recycling option. Transport to landfill presents savings in case study 2 owing to the cost derived from the skips' rental, which is a shorter period of time, and mixed waste volume, which has turned out to be smaller than sorted waste, meaning that a less number of skips are needed.

CONCLUSION

The main objective of this paper is to carry out an economic analysis of two case studies part of the GtoG project, where best deconstruction practices where monitored and studied. Given this, the investigated scenarios enable the following conclusions to be drawn:

- Deconstruction provides economic and environmental benefits coming from the savage of materials reused and from the disposal fees avoided, compared to the conventional demolition practices.
- Landfill tax is one of the crucial economic parameters identified as more impacting in the total cost that should be used to encourage deconstruction, and thus C&D waste recycling.
- The deconstruction practices applied on-site may lead to cost savings and enabling an effective dismantling, on- site sorting and loading.
- Deconstruction practices enabled almost the total recovery of all materials, but for a fraction due to the GtoG recycler's specific acceptance criteria.

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